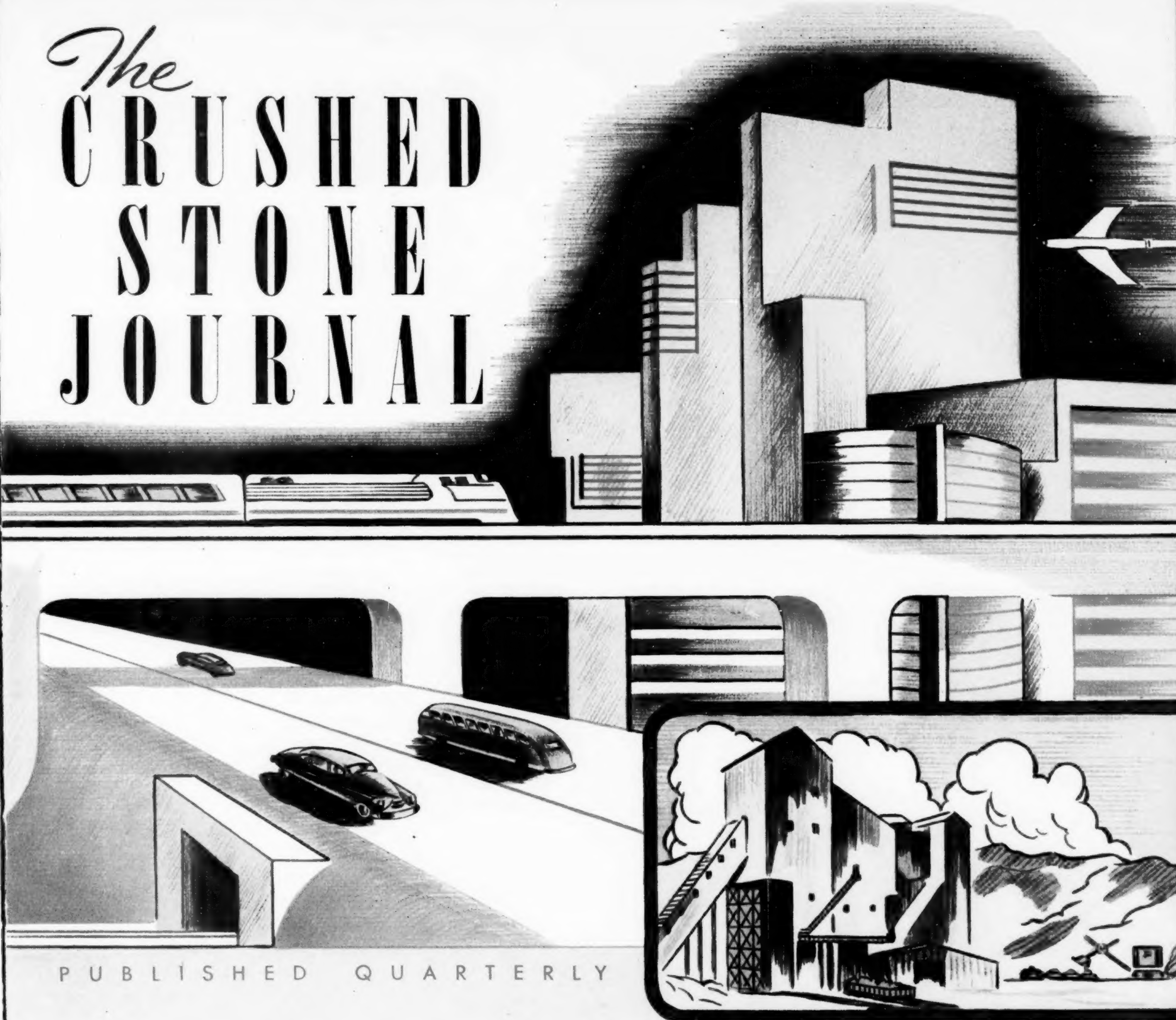
The CRUSHED STONE JOURNAL



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The Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

J. R. BOYD, Editor

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THE

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The U. S. Corps of Engineers Approach to More Durable Concrete[1]

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IN view of many turbulent events during the past several years, which have been closely associated with the evaluation and selection of concrete aggregates for the Corps of Engineers Civil Works Program, I feel very much akin to a crippled duck on opening day of the hunting season.

Seriously, since the day my good friend, A. T. Goldbeck, suggested the idea, I have been keenly interested in availing myself of the opportunity of speaking to members of the National Crushed Stone Association on the subject of "More Durable Concrete" particularly as it is related to top quality aggregates.

Many of the past misunderstandings between representatives of the Corps of Engineers and members of the important construction supply industry have stemmed from a somewhat obscure picture of the ultimate goal of the Civil Works Construction Program.

Scope of Constructon Program

The Corps of Engineers is an organization of builders. River and harbor and flood control works authorized by the Congress of the United States are assigned to us for execution. In all of these projects, with the exception of dredging operations, concrete is used to a greater or lesser degree. Consequently, this program involves the placement of many millions of cubic yards of concrete in all types of hydraulic structures in all parts of the United States. This concrete contains a wide variety of types of materials and is designed, manufactured, placed, finished, and cured with many new techniques and procedures which were unknown a relatively few years ago.

Need for Improved Concrete

Surveys of existing projects have indicated that concrete has not always proven a satisfactory construction material. Concrete structures in all parts of the country have shown an alarming lack of durability after a relatively few years of service. This non-durability can be caused by many factors. The ingredients used in the concrete, the mixing, placing, and curing operations can all be contributing causes to non-durability. As a direct result of this inadequate service record of concrete structures, unprecedented research programs in concrete technology are being initiated. Concrete laboratory facilities and techniques are being expanded; existing construction procedures are being improved and new procedures are being developed.

Due to the vast civil works program, the Corps of Engineers is in a position to assume and has assumed its rightful place in the field of advanced and improved concrete technology. It has adopted a policy of performing proper preliminary investigation, planning, design, and construction of all civil works projects.

[1] Presented at the 32nd Annual Convention of the National Crushed Stone Association, Hotel New Yorker, New York, N. Y., February 7-9, 1949.

In order for this policy to function properly and with the full knowledge of the responsibility of constructing such large-scale projects, involving substantial outlays of public funds, the Corps of Engineers is constantly striving to provide the best engineering solutions for the many problems assigned to it.

Approach to Improved Concrete

We maintain, as a branch of the Waterways Experiment Station at Vicksburg, Mississippi, a completely equipped concrete research laboratory at Clinton, Mississippi. This laboratory is the "proving ground" for all other Corps of Engineers concrete laboratories. Development and standardization of all laboratory equipment and procedures is accomplished here. The Concrete Research Division will spend, during the fiscal year 1949, approximately $300,000 on basic concrete research, special studies of air-entrained mass concrete and aggregates for such concrete, alkali-aggregate reaction, permeability, grouting, uplift, special cements, concrete forms and form linings, vacuum and prepakt methods, concrete pipe, and other products too numerous to mention.

In addition to the Concrete Research Division, we have established six regional construction materials laboratories in various locations throughout the United States. These laboratories are located at Atlanta, Georgia; Dallas, Texas; Oakland, California; Portland, Oregon; Omaha, Nebraska; and Cincinnati, Ohio, and they are being placed in full operation as rapidly as possible.

The primary function of all of these laboratories will be to conduct full investigations of all of the materials, including concrete aggregates, proposed for use in any civil works project and to submit test results of such investigations to the Office, Chief of Engineers, Washington, D. C., for approval prior to advertising the project for bids. These laboratories also perform many important secondary functions such as: the design of all concrete mixes, control of earth embankments, etc. In order to insure comparable results from all of these far-flung regional laboratories, the Office, Chief of Engineers maintains a careful and complete coordination program. Equipment and test procedures are carefully duplicated and frequent check tests are performed by all participating laboratories.

Before proceeding directly to the discussion of concrete aggregates which, I am sure, is of direct interest to you gentlemen of the crushed stone industry, I would like to mention briefly several events of the past few years that were initiated by the Corps of Engineers for the sole purpose of promoting more durable concrete for civil works structures through the medium of improved construction equipment and procedures.

Concrete Buckets

With the advent of air-entrained concrete, we discovered one thing quickly. Normal concrete buckets, commercial buckets that have been in use for years, would not satisfactorily handle lean mass concrete mixes with air. We endeavored to interest contractors in an effort to do something about it. We did not have much luck, so we endeavored to introduce the idea to the manufacturers of equipment, to see if they would approach it. They gave us one answer: "There are so few dams built, and so few 8-cu. yd. buckets used, that it would not pay us."

We still had dams to build; we were still getting segregation and improper deposition of concrete from buckets with air entrainment; so the Corps of Engineers, through its civil works investigation program, obtained ten thousand dollars and had one concrete bucket built to what we think are the proper specifications. Today, after less than a year, there are three commercial buckets on the market available to our contractors that will properly handle all air-entrained mass concrete. We hope there will be more.

I merely mention these things in passing to show that we have not concentrated entirely on aggregates in our effort to promote better concrete.

New Type Consistency Meter

We have very recently conducted a test on a new type consistency meter at Allatoona Dam, near Atlanta, Georgia. We have participated in this test to the extent of buying one from the inventor. He had tested it on 1 1/2-in. concrete. It worked satisfactorily. He had no way of knowing whether it would work satisfactorily on concrete containing 6-in. top size coarse aggregate, such as we use in dam construction. The meter has worked and is working very satisfactorily.

Vacuum Finishing and Prepakt Concrete

We are conducting experiments on vacuum finishing and prepakt concrete far above and beyond where the license holders of those two processes

now have gone. We like them; we want to use them; we must find out how to use them in our work.

In three weeks we will hold our second annual concrete conference for the Corps of Engineers Civil Works personnel in Kansas City. We are doing this for one purpose; we are building dams in all parts of the United States, under all conditions. We are using all types of aggregates in those dams. Once a year we feel that it is beneficial to us and to the construction industry to get together at some central location and spend three days discussing the problems which have arisen and the solutions we have endeavored to find for them during the past year.

I should like at this time to invite any or all of you gentlemen who might be in the vicinity of Kansas City to attend that conference on the 1st, 2nd, and 3rd of March. The program deals primarily with the cooling of aggregates, temperature control of concrete, and the manufacture of aggregates. Those three problems are now vitally important as we build high dams in the western part of the United States.

Concrete Aggregates

In discussng this subject, I would like to begin by re-emphasizing the present policy of the Corps of Engineers relative to the investigation and approval of any source of concrete aggregates for civil works projects.

It is the intent of the Corps of Engineers to use the best construction materials, including concrete aggregates, locally and economically available to any particular construction project. It is not the intent of the Corps of Engineers to require concrete aggregates of vastly superior quality at the expense of greatly increasing the cost of any project. Many factors, however, enter into the determination of what is meant by the term "locally and economically available". Obviously, a large multiple purpose project designed for important functions and expected to last for many years would justify the imposition of more rigid requirements for concrete aggregate than a smaller flood control structure which could be repaired or replaced in a relatively few years.

The scope of this policy includes two very important factors in the endeavor to obtain "more durable concrete".

(1) Quality of the material

(2) Mechanical gradation and uniformity of material

Quality. I would like to digress for a moment to answer a question which has been asked me so many times in recent years by engineers and aggregate producers. "If air entrainment has so greatly increased the durability of concrete, why bother about the quality of the aggregates?" The answer is simple. Air entrainment is no "cure-all". It does improve the durability of concrete but inferior aggregates or reactive aggregates remain inferior or reactive in the finished product. There is no substitute for top quality materials.

The determination of the quality of the material is, in some instances, two-fold. Both the "service record" of the material in concrete and the behavior of the material in concrete in laboratory tests play important parts in the determination of an approved source of aggregates for any work. Sometimes when the data on one of them is lacking, the other must be used in rendering a decision relative to the quality of the material.

Service Records. Service records must be extensive and complete and must be obtained from structures of comparable functions and degree of exposure to be valid.

It is very well to say that aggregates out of Mr. Jones' quarry have been used for twenty-five years in this vicinity to make concrete. That does not mean much. We must know much more than that. We should know much about the construction of that project, where the materials came from, the cement used, the mix design, and sometimes we should know who built it in order to draw any clear-cut interpretation of the way the concrete is today.

Consequently, when we examine service records and find the data lacking we turn to the one thing that we can depend upon to the best of our ability, that is, laboratory tests. These tests have been criticized very severely. I should like here and now to emphasize that we do not maintain that the laboratory tests we have developed and are using to evaluate concrete aggregates and approved sources of concrete aggregates are the best in the world. They are not. They leave much to be desired. But we do feel that these tests which we have developed and are using, and are gradually and constantly improving, are the best tests available today to show us the expected behavior of the material in concrete when we have nothing else to count on .

Laboratory Tests. As many of you are aware, the Corps of Engineers is unique in the respect that no

contract specification issued for civil works construction contains any performance limits for concrete or concrete materials with the exception of gradation and uniformity requirements for the concrete aggregates and the amount of air entrained in the concrete.

Gone are the conventional limits for sulphate and abrasion losses. Gone are the limits for absorption and deleterious substances. All reference to slump, concrete strengths, minimum cement contents, and maximum water contents have been deleted.

The absence of specific limits of any "conventional" nature in contract specifications for the Corps of Engineers civil works program is entirely intentional. It is a policy which was adopted after long and careful consideration of all factors involved. Regional variation in quality of materials and the variation in demand for quality from structure to structure and region to region is believed ample justification for such a policy. It is desired at this point to further emphasize that test results, as used by the Corps of Engineers, in evaluating acceptable concrete aggregates are used in a qualitative manner only. Actual quantitative results of laboratory tests have no particular bearing on the selection of concrete aggregates. To illustrate, any effort to establish a limit for magnesium sulphate, absorption, abrasion, or any other tests with the idea that any material meeting such a limit would be acceptable for use in concrete, or that all materials failing to meet it would be unacceptable, is a fallacy. It is only after all such tests have been completed on several different concrete aggregates that such results can be used to determine which materials are acceptable for the work. It is conceivable that concrete aggregates, which greatly exceed a normal absorption limit and which have a relatively high loss in the sulphate test, would still be acceptable for work contemplated in a particular area if this material compared more favorably than all other aggregates economically located when evaluated by the over-all test program.

Before outlining the Corps of Engineers test methods for determining the quality of concrete aggregates, I would like to "highlight" one fact. All of the test procedures used by the Corps of Engineers in evaluating the acceptability of concrete aggregates are tools only and are used as tools in the investigation to determine the acceptability of one or more materials over all others locally available for the work contemplated. No effort is made to simulate actual conditions to which concrete structures are subjected in the field.

We can determine and pick from a relative investigation conducted in this manner one, two, three, four, five, or six most suitable sources in that area which we can afford to use on that job. We feel that this approach is ample justification for specifications within our limits.

We approve, prior to advertising, suitable sources of aggregates. We do not close the door to other sources of aggregates. We cannot investigate them all. We will, however, investigate any economically located source of aggregates which is brought to our attention prior to the time the contract plans and specifications are issued.

It is admitted that much remains to be determined with regard to method of tests for aggregate selection and that the methods now available do not provide a perfect or uniformly conclusive basis for aggregate selection in all cases. It is, however, believed that the procedures used by the Corps of Engineers are the best which are available and represent progress over those which have been used in the past.

I will not go into detail on the routine "conventional" tests for concrete aggregates. I am sure you are all familiar with the tests for sulphate loss, specific gravity, absorption, abrasion, and mechanical analyses. Suffice to say that all of these tests are conducted and the results are carefully considered in the final approval of any material. But since we have been criticized in our approach for more durable concrete through the medium of controlling the materials and the construction of that concrete, I should like to bring out at this time some of the laboratory procedures which we have developed in part and are using today to determine whether or not a source is satisfactory.

We are more keenly interested in other tests, three, in fact.

(1) The physical properties and the mineral constituents of the material and the possibility of the occurrence of harmful chemical reaction between certain of these constituents and the alkali in the cement.

(2) The behavior of the materials in concrete when subjected to weathering tests.

(3) The thermal properties of the materials and their effects on concrete.

Petrographic Examination

The importance of geology and petrography were not fully realized in former years. These sciences are now essential elements of any complete aggregate investigation. The geology of the region in which the structure is to be built often exerts a major influence on the type of aggregates to be used since the selection of the material must, from economic necessity be limited to that region except in instances where a petrographic examination indicates the local materials to consist of extremely weathered, soft, porous or structurally weak elements or when it can be demonstrated that the materials contain deleterious amounts of chemically reactive constituents.

It is very important that petrographic examinations of the materials be made, and made first. They save us untold manual labor in the laboratory. Preliminary petrographic examinations can permit us to rule out sources of material immediately (and it does not take long to make one) which have physically weak constituents or which contain possible reactive constituents.

They tell us other things. In some areas where no gravel exists or where the maximum size of gravel is very small and we are concerned with mass concrete structures, we turn automatically and at once to crushed stone for coarse aggregate, quite frequently for fine aggregate, too. In some areas of the mid-continent, limestone is the only rock available to make crushed coarse aggregate. In parts of the North Pacific States volcanic rocks and sands and gravels from that origin constitute almost the only material that we have to use for concrete. In other areas such as the Gulf and Atlantic coastal plains, there is no large gravel at all and most of the gravel is chert. There is little or no consolidated bedrock. Therefore, we cannot make crushed coarse aggregate and we must learn to use this gravel.

Petrographic examination of proposed concrete aggregates usually consist of two phases.

1. *Preliminary Petrographic Analysis.* A preliminary investigation should usually eliminate from further consideration those sources consisting of extremely weathered, soft, porous, mechanically weak aggregates or those containing constituents which are known to be deleteriously reactive.

2. *Detailed Petrographic Analysis.* This analysis is much more complete and furnishes detailed data on the qualitative and quantitative presence of the individual rock and mineral types in the material. The importance of conducting a detailed petrographic analysis cannot be too strongly emphasized. As an example, a preliminary examination of test samples of ledge rock from two quarries located a few miles apart in North Carolina indicated that both materials were granite gneiss and both were apparently similar in nature. A detailed analysis indicated that while one material was a normal granite type, the other material had a well developed network of microscopic cracks. Elementary physical tests on these two materials developed no marked differences but when concrete specimens made with each were tested in freezing and thawing, those specimens containing the normal granite showed a durability factor of 75 after 300 cycles, whereas those specimens made with the granite containing microscopic cracks showed a durability factor of only 17. It must be concluded that the cracks permitted water to penetrate the aggregate particles and rapid failure in freezing and thawing was the result.

We learn many other things in petrographic examinations of aggregate prior to any other test. We learn about what we like to think of as the reactive constituents: such materials as opal (chemically amorphous silica), natural glass and artificial volcanic glasses, and chalcedony (our definition of that is interstitial material in microfibrous form of quartz), and it is fairly common in some areas.

In addition to the deleterious materials, the petrographic examination will show us many things about the physical properties of the aggregates. We like to think of most trap rocks and most granites as being good concrete aggregates. Some granites are extremely susceptible to disintegration from freezing and thawing. Some trap rocks contain alteration products that cause the rock to swell and disintegrate in water. Some of the basalts contain natural glass that will react deleteriously with the minor alkalies in cement. Some schists are weathered and contain well developed planes of weakness which provide access for water and consequent disintegration. Some quartzites are bonded by opal. Most andstones are very porous.

Some limestones contain interbedded shale and chert, and some of them also contain very thinly bedded separations filled with clay. So much for the petrographic part of our laboratory tests.

Thermal Properties of Aggregates and Concrete

In briefly discussing why we make thermal studies, or why this hue and cry over thermal properties and the studies of coarse aggregate, I would like, as an engineer, first of all to justify this study. It is conducted principally for the purpose of determining the proper technical approach in designing a mass concrete structure as economically as we can, but still one that will be durable, impermeable and monolithic, and one which will resist all forces acting upon it.

Thermal properties properly fall into two classes: structural—which pertains particularly to the dam itself, to temperature rise of the concrete, and to the coefficient of expansion of the concrete; material—such as the differential coefficients of thermal expansion of ingredients of the concrete, the diffusivity and specific heats of concretes and aggregates, and the thermal properties related to the hydration of cement.

While the design and control of mass concrete mixes to reduce temperature rise and consequent volume change and attendant cracking play a vital part in the production of a more durable structure, time does not permit me to discuss that phase of it here. I would like, however, to discuss what effect we think the thermal properties of the material have on concrete, and in what way these properties react to cause inferior concrete.

Coefficient of Thermal Expansion

In the design of a major concrete structure, such as a dam, the coefficient of expansion of the concrete is important in the calculation of stresses in the concrete and the abutments due to temperature changes. The primary factor controlling the coefficient of expansion of mass concrete is the coefficient or coefficients of expansion of the aggregates—principally the coarse aggregate—since the aggregates comprise between 80 and 90 per cent by weight, of mass concrete. These values may run from about 3 times 10^{-6} for most limestone to 7 times 10^{-6} F. for a siliceous aggregate having a high coefficient of thermal expansion.

In this connection, laboratory tests have shown that differences between the coefficients of expansion of the coarse aggregates and the mortars show an inverse relation to the durability of the concrete in severe weathering exposures. It must be concluded, therefore, that a large difference between these coefficients should be avoided since the stresses set up at the interfaces of coarse aggregate particles and mortar can be sufficient to cause loss of bond and radial cracking from the interface which will eventually destroy watertightness in hydraulic structures.

We have found in laboratory studies in many cases that where that difference is more than 3, we can expect a rapid breakdown of any concrete specimens that we care to subject to freezing and thawing. The term "thermal compatability" was cooked up, as was "marriageability of aggregates" in an attempt to explain why we had certain failures of concrete specimens under weathering tests in the laboratory. It is not used now; it has never been used as a means of selecting concrete aggregates in civil works projects.

Thermal Diffusivity

Thermal diffusivity is another factor we must know in designing large dams. This property is a measure of the rate at which heat will be lost or gained by the concrete. It is used in computing the time necessary for a structure to attain final temperature, and the rate that it will cool or heat due to external thermal influences. The thermal diffusivity of the concrete is dependent principally upon the type and the amount of aggregates in the concrete. Values for this coefficient vary from about 0.030 $ft.^2/hr.$ for concrete containing basalt aggregates to about 0.125 $ft.^2/hr.$ for concrete containing chert aggregates. It will take, therefore, several times as long for a comparable temperature change to occur in the former concrete as in the latter.

Specific Heat

There is one other property we determine in the laboratory on thermal studies and that is specific heat. Specific heat is a measure of the capacity of a substance to store heat. A knowledge of the specific heat is necessary in calculating the theoretical adiabatic temperature rise from the heat of hydration of the cement. A high specific heat is of great advantage in mass concrete since it limits the temperature rise.

Alkali Aggregate Reaction

I have mentioned briefly the possibility of materials, many of them, whether they are crushed, manufactured aggregate or natural materials, having deleterious substances that might possibly react with the alkali in the cement to cause destructive growth

and cracking. We use in the laboratory two methods to determine whether or not a concrete aggregate could be expected to be reactive when combined with a cement. One which I am sure most of you are familiar with is the American Society of Testing Materials mortar bar expansion test, which provides as follows:

Length Change, per cent	Reactivity
0.002 or less	Non-reactive
0.02—0.04	Negligible reactivity
0.04—0.10	Probably reactive
0.10—over	Reactive

The main objection to the test is that it takes from a year to eighteen months to find out anything. Usually we have to get information yesterday to approve the aggregate today. The other method we use for determining reactive materials is a slightly modified version of the accelerated chemical test proposed by the Bureau of Reclamation.

No one test of alkali reactivity of aggregates has yet proven sufficiently dependable to suggest that it can be used alone in judging the suitability of aggregates for use in concrete structures. It is necessary to evaluate the combined findings of petrographic examinations, mortar-bar expansion tests, and accelerated chemical tests to find a basis for acceptance or rejection of aggregates.

Weathering Tests for Concrete

Accelerated Freezing and Thawing Test. One of the most criticized procedures which we have in the Corps of Engineers for determining whether or not concrete may be expected to be durable is our accelerated thermal shock test or accelerated freezing and thawing test. I would like to emphasize once again that we do not in any way attempt to simulate actual conditions. This test was developed, in reality, from actual experience we gained in some work at St. Augustine, Florida, and Treat Island, Maine, working with rock types and concrete specimens with a great variety of aggregates, with and without air entrainment, different types of cement, and many other factors.

Twice every twenty-four hours those specimens were submerged by the rising tide. Twice every twenty-four hours those specimens were left in a drying condition by a receding tide. In Maine, particularly, that meant that we obtained in the winter months two cycles of freezing and thawing every twenty-four hours.

That test has been running for a great many years and we have learned lots from it. But that is too slow for us. We must have a method to determine in some way the expected performance of that material in concrete, rapidly, so we developed an accelerated freezing and thawing test. In this test we subject specimens of concrete made with the materials that we are testing to a temperature range from 0 to 40 F. twelve times a day. That is rapid, I admit, and it does not simulate actual weathering conditions. However, it does give us an opportunity to run 300 or more cycles of rapid freeze-thaw tests on concrete in a relatively short time in order to get a comparable basis between one combination of aggregates and another. Again I say no attempt is made to put an actual quantitative interpretation on these test results.

Heating-Cooling-Wetting-Drying Test. We have long felt the need for another test in addition to the freeze-thaw test, which has been criticized so frequently, and in this manner, that much of our concrete is not exposed so much to weathering, or even thawing and freezing in any respect. We admit that; we realize it. Consequently, we have gone into two of our laboratories and developed a non-freezing weathering test. One method was to heat and dry the specimen and then to wet and cool it, in alternate cycles. The other method was vice versa.

We found in one of those pilot tests that we had developed only a new and better method for curing concrete. Its durability increased rather than decreased. The other method, however, shows great promise and within the next year we hope to have it standardized and in use in these six regional laboratories in all parts of the country. That will be used primarily to combat the criticism we have had so far that much of our concrete is not exposed to freezing and thawing.

Gradation and Uniformity of Concrete Aggregates

I am sure that many of you are familiar with the gradations requirements in the Guide Specifications for Concrete for Civil Works. Some of you are familiar with the more recent modifications of these requirements which have appeared in contract specifications for dams now being advertised.

These modifications have been accomplished as the result of experience in the production of aggregates and the design, manufacture and placement of concrete.

I will not presume to tell you gentlemen of the crushed stone industry that we know all there is to know about concrete aggregates. We are learning, however, and learning the hard way.

It has been less than a week since I was on a job which was shut down tight. That job was shut down for more than one reason, but the prime reason was to obtain a better concrete aggregate from granite.

Formerly, and not so many years ago, we felt that we must have fines, "rock flour" in the concrete to improve the workability or the lack of workability which is inherent in all crushed stone, and to permit the decrease in cement content to decrease the heat of hydration. Since the advent of air entrainment, we have learned that "excess fines" is a mistake. We required as much as 10 or 15 per cent of minus 100 material, and a good bit of the minus 200 material to be maintained in the fine aggregate storage pile and be carried through the batching plant into the mixer.

We have now found that is wrong. On one job that I have in mind, we are going so far as to modify the contract gradation requirements from about 12 per cent minus 100 material to about 3 per cent minus 100, which includes minus 200 material down to pan. We would like to have made this 0 per cent minus 100, because we have found that by transfer from storage piles to the batches and from the degradation in the mixer, that we were manufacturing as high as 18 to 20 per cent of minus 100 material in the concrete mixes that went into the forms. That was too much. As I say, we learn things the hard way and we change our minds, but we are learning.

We are manufacturing aggregate or inspecting and supervising the manufacture of aggregates from limestone, quartzite, granite, trap rock, diorite, and basalt, and are processing natural aggregates from almost every type of natural deposit that you can imagine.

One of the primary considerations for more durable concrete, and one which we can—and I am speaking to you as the crushed stone industry—do something about, is gradation, particle shape, and uniformity. Our specification gradations and uniformity requirements are rigid. They were planned that way. We can get any gradation for fine aggregate we require if we have enough money in the U. S. mint to pay for it. We cannot afford that. We do not want to impose hardships on contractors or aggregate suppliers. We are involved in constructing mass concrete dams, some of which are over 400 ft. high. If we eliminate forced cooling as was used at Boulder Dam, in these structures, we can save millions of dollars but, we must control the placing temperature of the concrete and we must reduce the sand, cement, and water content of the mixtures to the absolute minimum consistent with proper placeability. Air entrainment has helped. Careful control of gradation and uniformity requirements will do the rest.

Boulder Dam could not have been built without forced cooling. I worked with the Bureau of Reclamation and I know some of their problems—and they have many. They do not have the problem of manufacturing aggregates, however. They are located in a region where they can usually find suitable sands and gravels for concrete aggregate.

We not only have the problem of manufacturing concrete aggregates but we like manufactured concrete aggregates. Practically every job of any size we have under construction today is using either the coarse or fine aggregates or both manufactured from stone, and we all feel that procedure will continue to grow if our civil works program continues to exist.

Low water-cement ratios in lean mass concrete mix design are vital if we are to maintain durability, strength, and impermeability. A high water cement ratio in lean mass concrete mixes permits the entrance of water or the passage of water through the concrete in three ways, any one or all of which are extremely detrimental to that concrete: first, passage or percolation of water through concrete by inter-sand voids which grow in size with the increase in water-cement ratio; second, the high water-cement ratio film which exists on the underside of large particles of crushed stone or gravel invariably contain voids which will readily permit passage of water; and third, bleeding of the concrete itself.

In order to obtain low water-cement ratio concrete, the gradation, particle shape, and uniformity of concrete aggregates, particularly the fine aggregate must be carefully controlled. A large quantity of minus 100 material in the fine aggregate inhibits the entrainment of air and increases the demand for water. This also holds true when the sum of the percentages between the No. 30 and No. 100 sieves is not sufficiently high. If the sum of the percentages between the No. 4 and No. 16 sieves is not maintained low, the mix is harsh and the demand for water is increased.

(Continued on Page 30)

The Use and Abuse of Seal Coats[1]

By C. V. KIEFER

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As the long morning shadows crept toward the base of the Ruby Mountains, erasing as they receded, the traces of October frost on the newly laid plant-mixed pavement, Isador Rich, the contractor, flourished his '48 Cadillac to a stop on the shoulder. As he stepped from the car, with the heater purring full blast, he glanced toward the east and subconsciously noted the golden-leaved quaking aspens sprawled on the mountain slopes. Turning up the collar of his tweed sports jacket against the fall nip in the air, he made a mental note that he would have to crowd things to get the seal coat applied and the job accepted before winter.

At the approach of a red Chevrolet "pick-up" from the west, Izzy wheeled and flagged down Johnny Wise, the Resident Engineer.

"Mornin', Johnny," chattered Izzy.

Johnny stumbled from his unheated conveyance and with numbed fingers fumbled for a cigarette.

"Hi, Izzy," he replied.

With shoulders humped, hands in pockets and backs half-turned to the sun's faint warmth, the following conversation ensued:

Izzy: "Little crimpy this morning."

Johnny: "Yeah, sure is."

Izzy: "Guess I'd better get going on the seal coat while the weather holds out."

Johnny: "Yeah, guess you'd better."

Izzy: "How about startin' Monday? Guess we'll be ready by then. Finish plant work tomorrow."

Johnny: "Guess that's okay."

Izzy: "Okay to use 200-300?"

Johnny: "Yeah, guess so. The specs include it."

Izzy: "I figure I'll have about 6000 gallons left in the pit. How much more will we need?"

Here Johnny digs out his dog-eared copy of the specifications and reads that under item "Seal Coats" it provides for use of SC-6, 200-300, MC-4 or 5, RC-4 or 5, and RS-1 at discretion of Engineer at rate of .15 to .25 gal. per sq. yd. and 20 to 25 lb. of 3/8 in. No. 6 rock. So he averages oil at .2 and rock at 22 1/2 lb. and does some scribbling on the back of an envelope.

Johnny: "Guess you'll need about 3 more 10's."

Izzy: "Okay, I'll go into town this morning and get it rolling."

Johnny: "Okay."

Izzy: "I guess we got about 2000 tons screenings stockpiled. We robbed 'em for that detour. 2000 enough?"

Johnny does some more scribbling at 22 1/2 lb. per sq. yd. and says:

"Yeah, guess that will do it."

Izzy: "They may be a little damp from that storm three weeks ago. Think they'll be okay?"

Johnny: "Yeah, guess so. They'll dry out on the road. Don't forget specifications say no oiling until temperature is 50 F."

Izzy: "Yeah, I know. Think we'll get it?"

Johnny: "Yeah, I guess so—by 10 o'clock anyway."

Izzy: "Will that old distributor we used on the detours be okay? The new one is down on the Las Vegas job."

Johnny: "Yeah, I guess so. The old crate looks like hell but she seems to spread pretty good."

Izzy: "Anything else?"

Johnny: "No, I guess not."

Izzy: "Okay, then, guess I'll get rollin' and order the oil. So long."

Johnny: "So long. See you Monday."

Gentlemen: That seal coat job was "engineered" by 13 guesses, and 13 is an unlucky number. Exaggerated? Of course, but, unfortunately, in far too many cases, not very much. Of course, this conversation and location are purely fictional and could never have happened in Nevada, but we happen to be here, so let's proceed.

Well, what happened to that seal coat job later? You can well guess. Screenings whipping off, bleeding in June, corrugating in July. Maintenance Department frantic in August, etc.

What should have been done?

WHY AND WHEN TO SEAL

Why

In the first place, never put on a seal coat until you are *sure* you need it.

[1] Presented at the Second Nevada Asphalt Forum, Carson City, Nevada, November 18, 1948.

You are only *sure* you need it if it is necessary to accomplish one or more of the following:

1. To seal moisture and air from entering the pavement
2. To non-skid the surface if slippery
3. To rejuvenate or enliven a dry or weathered surface to improve wear resistance
4. To improve luminosity or night visibility
5. To reinforce and build up pavement structure
6. Traffic lane demarkation (rumble)

The type of seal I am talking about is one application each of asphalt and fine aggregate. Armor coats, surface mulches, etc. are in a separate category and topics unto themselves.

When

1. In good weather. One government agency in a survey of seal coats classified as "excellent" found that between 85 and 90 per cent were done in June and July. Of those classed as failures, 60 per cent were done after October 1st. In other words, you have less than a 50-50 chance of getting a good job on work done in late fall. Can you as engineers afford to "buck" such odds? I think not.
2. Seal at the first sign of distress or need for any of the factors listed above.

When NOT to seal:

1. To cover up sins of omission and commission which should not be permitted in the first place.
2. To try to correct corrugations or cracking due to base failures.
3. To try to correct pushing or shoving due to unstable mixtures. A seal will not cure these things.
4. Do not seal unless you are *sure* it is needed.

HOW TO PROCEED

After you are sure you need to seal, how to proceed and what to think about, will now be considered.

While the asphalt content of a premix pavement is usually very carefully determined in terms of aggregate voids, surface area, stability, and the like; it has been all too common practice to decide on the quantity of asphalt for sealing, or surface treatment, by eye, or rule of thumb—or by guessing. The asphalt requirement for surface sealing with a given aggregate should be as carefully proportioned as in the case of any other type of bituminous surfacing.

The amount of asphalt required in a surface treatment course bears a definite relationship to the percentage of voids in the layer of covering aggregate, but no attempt should be made to provide sufficient binder to fill all the void space. The one great advantage which surface sealing has over nearly all other types of bituminous paving is that with surface sealing, although sufficient binder to fill only 50 to 70 per cent of the voids between the stones is applied, nevertheless, the road will be thoroughly sealed and waterproofed, while the rock particles are held securely in position. If the asphalt fills half the voids, or in other words, rises to half the height of the layer of stone, then a strong waterproof mat of rock and asphalt will cover the roadbed and at the same time the top half of the stone will present a mosaic non-skid surface.

The New Zealand Approach

Now, how to arrive at that correct relationship. Various agencies have studied the problem but none seem to have carried it to a satisfactory conclusion any better than did F. M. H. Hanson of New Zealand some 12 or 15 years ago.

Hanson, correctly observing that the right amount of asphalt to fill a portion of the voids, depended on the characteristics of the cover stone, has given us, through his research and studies, two means of employing an engineering approach to the problem.

One of these is more or less approximate, but much better than guessing, and consists of calculating the compacted depth of stone as a percentage of the loose depth.

Hanson found that with average conditions, which include size and grading of aggregate normally used, the voids in a loose layer of screenings on the road can be taken as 50 per cent of the average depth of the aggregate. The average thickness of a loose layer of cover stone is found by dividing the volume of the screenings by the area of the road covered. This, of course, assumes a nominal spread to completely cover the surface with an allowance of not to exceed, say 15 per cent, for whip-off. This loose depth is reduced when the screenings are compacted under rolling and is still further reduced under the compaction of traffic. The first reduction in volume (or depth) occurs in a short space of time, and is comparatively great, whereas the compaction which takes place under traffic is relatively small and occurs over a long period of time.

For practical purposes, the voids in the roller compacted cover coat aggregate may be taken as 30 per

cent, while in time there are about 20 per cent voids in the traffic compacted aggregate. So, for example, if the average depth of a layer of cover coat aggregate after the final compaction is 1/2 in., then voids may be considered as a depth of 1/10 in. (20 per cent of 1/2 in.) and if a film of asphalt of this thickness is applied to the road, the asphalt will ultimately rise to just the average height of the chips. Experience has shown that the stone will certainly be held in position if the asphalt is not less than 50 per cent nor more than 70 per cent by volume of the void space.

Further, the ultimate compacted depth of a layer of loose screenings equals about 62 1/2 per cent of the average net loose depth, which is the volume of stone less the allowance for traffic whip-off divided by the area covered.

Hanson, finding that the above method of calculating the compacted depth as a percentage of the loose depth was not altogether satisfactory, devised a more accurate method:

The coverage value of the aggregate for the area which will be covered by one cubic yard when spread one stone thick and with the chips shoulder to shoulder is not always known. Yet, there is a simple, definite and accurate method of determining the compacted depth of sealing coat aggregate. No stone chips are so regular in shape that each chip does not have one dimension less than every other dimension. *It is the average of these least dimensions of the chips forming a cover coat aggregate which determines the average compacted depth.*

A close examination of a sealed surface will reveal that all the chips are lying on their flats, so that their least dimensions are the height of the upper surfaces of the chips above the original surface.

This least dimension of a stone chip can be readily determined by caliper measurements. By measuring individual pieces of a representative sample of cover coat aggregate, the average least dimension is ascertained as well as the range of least dimensions occurring in the material. The average least dimension of sealing chips is a most important factor, as cubical chips may have the same screen analysis as very thin "flattish" chips, but the coverage value and especially the compacted depth will be quite different. The thin "flattish" chips might be spread at the same rate per square yard as the cubical chips, but in the case of the former there will be a much greater whip-off since the chips adhere only one stone thick. Screen analyses are an approximate guide when the general shape of the chip is known. It is usual to call for angular chips free from thin or elongated pieces, but just when is a chip thin? No matter to what loose depth chips are applied, provided they are not too small and "flattish," and provided they are spread shoulder to shoulder, the compacted depth will remain constant. In other words, heavier applications of chips mean only a higher percentage whipped off under traffic.

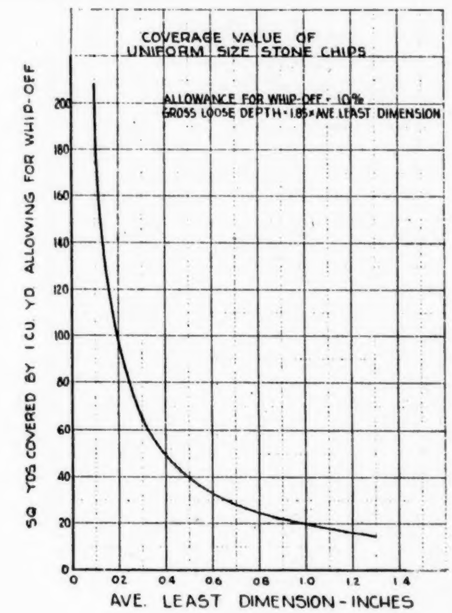

FIGURE 1

Relationship Between Average Least Dimension and Coverage Value with Allowance for Whip-off

The compacted depth or average least dimension is 62 1/2 per cent of the net loose depth, and therefore the average least dimension of any chips multiplied by 1.6 will give the minimum loose depth of those chips from which the minimum volume may be calculated. Unless chips are of a very uniform size, it is not practical to spread so there will be no whip-off. In practice, an allowance of about 10 per cent to 15 per cent for whip-off and perhaps some small wastage in handling should be made. To cover such losses the average least dimension should be multiplied by at least 1.85. This gives the gross loose depth from which the volume required for any area can be obtained. Figure 1 shows the relationship between the average least dimension and the coverage value with an allowance for whip-off.

The importance of the average least dimension of the aggregate for surface sealing will now be apparent. It enables the coverage value of chips for

average spreading to be calculated. It gives the compacted depth of the chips as sealing cover coat, and since the compacted layer of aggregate contains 20 per cent of voids, the amount of bituminous material necessary to rise to any height around the stone can be readily determined.

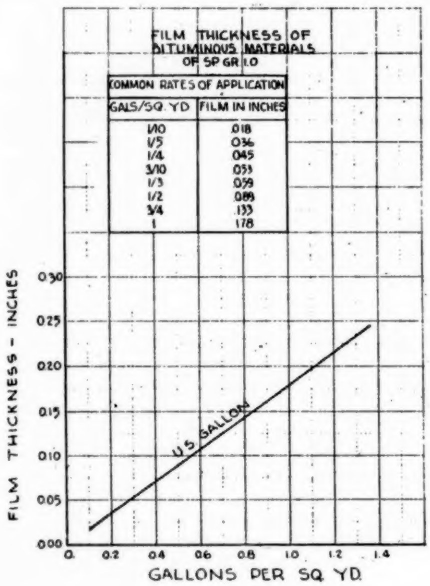

FIGURE 2

Relationship Between Film Thickness and Gallons per Square Yard

In calculating the quantity of bituminous material for surface sealing it is necessary to convert the depth of film required into gallons per square yard or vice versa. A graph and table for this purpose is given in Figure 2. *The quantity of bitumen should not exceed 70 per cent of the void space in the compacted cover coat aggregate.*

In determining average least dimensions of fragments in a sample of cover coat aggregate, it will be found there will be a range between the lower and upper limit in least dimensions which it is desirable to keep below 1/2 in. Vibration of vehicles will begin to be apparent if the least dimensions of the individual chips of a cover coat aggregate vary by 3/4 in., and the vibration becomes uncomfortable when the variation exceeds 1 in. This is especially true for lighter type vehicles. This feature can be deliberately created for traffic channeling—particularly as a warning on shoulders under night driving.

Asphalt Requirement

We have been considering only the amount of asphalt required to seal a uniform, smooth, nonabsorptive, unyielding surface, from the standpoint of the correct amount under these conditions to fill from 50 to 70 per cent of the voids in the aggregate cover coat. There are, however, three and possibly four variables which must be considered. These are:

1. The amount of asphalt to seal the surface and provide from 50 to 70 per cent to fill the voids as discussed above.
2. The amount of asphalt required to prime the existing road surface if dry and absorptive and bring it to a uniform condition. This requires additional asphalt over and above that noted in item 1 above.
3. The porosity or absorptive qualities of the cover aggregate itself.
4. To a much lesser extent, the roughness and surface texture of both the existing surface and the individual particles of cover stone.

There must also be considered that type of soft or yielding surface wherein embedding of the cover aggregate can be expected in a relatively short time under traffic. This is most likely to occur on extremely fine graded mixes, or "fat" surfaces. I know of no substitute for experience when sealing such a surface. The above theories of relationship of asphalt to void space do not work on such over-rich old surfaces because the voids in the cover stone are ultimately filled with a portion of the old road surface. One can only say that under these conditions, the asphaltic seal should be applied very sparingly indeed as it functions more or less as does the glue in a mortise and tenon joint in woodwork, than as a seal coat in the accepted sense.

The amount of oil required to prime the old dry surface must also be arrived at somewhat experimentally; or, if too badly weathered, perhaps the seal should be split into two shots with a different type of oil on the first application, to bring the old surface to a uniform condition. In any event, the amount of residual asphalt over and above that required to prime must be left on the surface to hold the screenings, as outlined above.

An idea of the absorptive quality of cover aggregate and hence additional oil required may be determined by such a method as advocated by Hveem in testing the coarse fraction in the C. K. E. test; that is, the retention of S. A. E. No. 10 Motor Oil when the screenings are soaked therein.

The item of roughness of surface texture of the old road surface, unless extreme, can probably be ignored in most instances as the bracket, or tolerance, of 50 to 70 per cent is usually sufficient to care for this variable. If not, this additional demand must also be determined.

Type of Asphalt

There is a relationship between the size of aggregate one can expect to hold and the viscosity of the asphaltic binder. This relationship is shown in Table I.

TABLE I
Cover Materials Suitable for Use with Different Asphalts

Seal Coats and Surface Treatments	Liquid Asphalts														Paving Asphalts	
	RC					MC				SC			Emulsions		150-200	200-300
	1	2	3	4	5	2	3	4	5	3	4	6	RS-1	RS-2		
Coarse sand cover	x	x				x	x						x			
Clean ¼ in. aggregate cover		x	x	x			x	x				x	x	x		x
Clean ½ in. aggregate cover			x	x	x		x	x	x			x	x	x	x	x
Clean ¾ in. aggregate cover				x	x			x	x			x	x	x	x	x
Graded gravel aggregate cover						x	x			x	x					

(*Note:* Choice in size of screenings will depend somewhat upon the objective but for general usage there seems to be a trend, in California at least, to a compromise between 3/8 in.-No. 6 and 1/4 in.-No. 10 by specifying a medium fine screening 5/16 in.-No. 8. The 1/4 in. (fine) are troublesome to produce and have a tendency to pad and develop ripples quite readily, whereas the 1/2 in. (coarse) and 3/8 in. (medium) may be a little on the coarse side for general usage. The objective to accomplish, together with characteristics of local deposits and cost of production will be the determining factors in the final choice of maximum size and gradation.)

Good seal coats have been laid with all of these combinations. However, let us suppose that henceforth and forever, we were to be told that *one* and *only one* asphaltic product (as they now exist) was to be available for seal coat work. Which one would we choose?

First, let us analyze the desirable properties:

1. It should be reasonably practical and economical; that is, it should be a product which can be produced by normal refinery operations and not some expensive, hand-tailored drugstore concoction.
2. It should be as fool-proof as possible; that is, easy to handle and apply and dependent upon the vagaries of nature and the human element to the least possible extent.
3. It must develop sufficient viscosity quickly to hold the screenings; that is, it must cure or dry quite fast so that the least amount of inconvenience to traffic will ensue, and also the least amount of injury or loss of screenings will occur under traffic during the seal's early life.
4. It should preferably be a product on which a viscosity of from 75 to 150 sec. S. F. can be obtained at the spray nozzle, without excessive heating.
5. It should have some "flow" characteristics immediately upon application to the surface but not for over a few seconds; that is, some "flattening out" is desirable to ameliorate unequal distribution, but, on the other hand, this feature must not be so pronounced as to permit the binder to continue to flow on transverse or longitudinal grades.
6. The residual asphaltic seal, after curing or drying, must not become excessively brittle at low temperatures nor, on the other hand, should it ever acquire a lower viscosity than about 1500 sec. S. F. at the highest road temperature which can be expected.
7. It should penetrate or grasp the old surface sufficiently to secure a good bond and seal surface voids and/or cracks, but not be so thin as to continue to penetrate or "migrate" after curing.
8. The residual asphalt content must be high enough so that for the needed residual deposition on the road, no excessive application entailing temporary submersion of cover aggregate is required.
9. It should preferably be able to "kill" a small amount of dust and still bond either to the old surface or the cover aggregate.

To return, now to the question of a choice of one and only one product to meet the most of these various demands under all conditions for seal coat work only, what type of asphaltic product is indicated? And here, no doubt, the argument will start. To get in my "two-bits" worth before becoming submerged, I'm going to pick RC-4.

Fortunately for you, the user, the choice need not be so restrictive. However, your choice, whatever is indicated, should be arrived at by a similar line of reasoning adapted to your particular case.

Accomplishment of a Seal Coat

After the basic ingredients and their relative proportions have been decided upon, the next step is how to proceed to accomplish the desired results.

There are three basic steps in the accomplishment of any type of seal coat work. They are:

1. Cleaning the existing road surface
2. Uniformly applying the asphaltic binder
3. Uniformly applying and consolidating the cover aggregate

Easy to say, but not so easy to do.

The first step is obvious but often slighted. Very

little dust, dirt, mud or other foreign matter can be tolerated, either on the surface to be sealed or on the individual particles of aggregate. Cleanliness at this point is probably not even second to godliness. In any event, the surface must be scraped, broomed, flushed, either mechanically or manually, as necessary to secure the desired result. You are all familiar with this tedious chore and perhaps the least said the better.

The second step, however, of uniformly applying the asphaltic binder cannot be skipped over so lightly. It is not enough to say the bituminous seal material shall be applied by pressure spraying at the predetermined rate and at the specified temperature range. This must be further amplified by certain other "musts":

a. The nozzles must be set at the proper height and kept there.
b. All nozzles must be kept clean and working properly.
c. Valve action both on and off must be instantaneous.
d. Proper lapping and not over-lapping of joints must be carefully watched.
e. Proper temperature must be consistently maintained at the spray bar level.
f. All areas unavoidably missed must be immediately hand-sprayed at the specified rate.
g. The exact coordination of pressure, capacity, and speed to produce the specified rate of application must be consistently maintained.

There are certain aids to securing the desired results which are within the power of the engineer such as the use of building paper at transverse joints, setting guide markers for equipment drivers, setting guide markers for limits of the load, insistence upon maintenance of straight driving, etc., but, I am sorry to say, that in most instances the engineer is almost wholly at the mercy of the particular distributor being used and its operators. This is not good but there seems little we can do about it until the perfect distributor is built.

As engineers, we can do a few things, however, such as specifying certain features of the distributor including a full circulating spray bar, accessible pressure and temperature gauges, tachometers, and uniformity of application for both the spray bar as a whole and also each individual nozzle. In regard to the latter, much can and should be done. In the U. S. the best type of nozzle to my knowledge is the conical type. They should be mounted staggered with 50 per cent overlap on a dual type spray bar. I understand that Argentina has perfected a slot type in which the slot is oval shaped and carefully machined for uniformity of spray. There may be others, but we all know the ordinary slot type used so frequently in this country leaves much to be desired.

You may think the application of asphalt is uniform, but are you *sure?* For example on one test job of which I am aware and on which all participants knew it was a test and were doing their best, the spread, measured at various intervals throughout the output of the distributor load, varied from .13 to .19 gal. per sq. yd. when .17 was desired. This, mind you, under especially carefully controlled conditions. On the same test, the spread of screenings varied from 17 to 45 lb. per sq. yd. when 22 lb. were desired. Unusual? Not at all, in my opinion. In fact, probably much more accurate than the usual results. Try, sometime, putting a one square yard piece of some thin material at the quarter points in the line of spread, weighing it before and after application, and you will see what is meant. I'll wager you'll be disagreeably surprised.

Also, try testing the full length of spray bar. This may be done in different ways, such as with the use of paper cut into longitudinal strips and comparing the difference in deposition on the various strips. A variance of more than 10 per cent should be enough to condemn the distributor. In various foreign countries a compartmented box has been used successfully similarly to test uniformity. The point is, lateral uniformity should not be taken for granted, neither should uniformity of individual nozzles.

The third step consisting of properly applying and consolidating the cover aggregate, as you all know, can "make" or "break" any seal coat job. By skipping over this phase of the work rather lightly, I do not mean to minimize its importance. However, in the interests of brevity, only a few pertinent features will be emphasized.

a. Mineral aggregate should be applied as soon as possible on the freshly applied bituminous material, regardless of type.
b. The screenings should be sound, uniformly graded from coarse to fine, and free from thin or elongated pieces.
c. Apply screenings by backing the truck and chip spreader. The use of modern spreaders for accuracy and uniformity of application, is strongly recommended.
d. If item c is properly done, very little broom dragging should be necessary. In any event, disturb the original deposition as little as possible but, of course, uniform and complete coverage is necessary.

e. Roll as soon as complete coverage is secured the same day in which the screenings were applied. Steel-wheeled rollers may be used if the surface is smooth enough but generally a pneumatic-tired roller will do the best job. Avoid over-rolling, particularly with steel-rollers.

f. Do not be in too much of a hurry to open to traffic, if possible to wait. In any event, give the bituminous binder a chance to "set-up" by controlling abusive traffic during the seal's early life.

Miscellaneous Considerations

1. Quantity of cover stone should be corrected for specific gravity if specified by weight. After all, the functional relationship is one of volume.
2. Residual deposition of asphalt must be taken into consideration if the solids content of the asphaltic binder used is less than approximately 80 per cent.
3. Rate of curing versus intensity of traffic must be considered and the surface protected during its early life with controls if necessary. In other words, the time element must be considered.
4. Temperature-volume correction as it affects resultant volume of the asphalt at road temperature, must be applied.

SUMMARY

To summarize the things which must be considered in the construction of a good single shot seal coat, ask yourself these questions:

1. Am I *sure* the surface needs an application of asphalt and screenings?
2. If so, what do I expect to accomplish:
   a. To shut out air and water?
   b. To non-skid?
   c. To rejuvenate or enliven?
   d. For improved luminosity?
   e. For reinforcement of pavement structure?
   f. For traffic lane demarkation?
3. Am I reasonably sure of success at this time of year?
4. Am I trying to make a seal coat do a job it is not suited for—to correct base failures, unstable mix, etc.?
5. Have I determined the proper residual asphalt film thickness with relation to aggregate voids?
6. In arriving at the film thickness, have I considered:
   a. Absorption of existing road surface?
   b. Porosity and absorption of aggregate?
   c. Surface and aggregate roughness?
7. Will traffic embed the cover stone in the existing surface?
8. Have I picked the best type of asphaltic medium for the conditions I have to meet?
9. Is the surface as clean as it is practical to get it?
10. Have I checked the distributor and nozzles for uniformity of application?
11. Likewise, the screening spreader?

In the foregoing, I have not, perhaps, covered fully every detail and ramification in seal coat work, but have attempted to point out various important features often overlooked or slighted. I have also attempted to point out certain considerations, remedial measures, and procedures which I hope will stimulate your thinking and, if followed, may result in better seal coats. In other words, if, through this harangue, you have been aroused to the necessity of "engineering" seal coats instead of "guessing" them, the objective of this paper will have been accomplished.

PRA Requested to Make Study on Rural Local Roads

Recently, on behalf of the Committee on Public Works, of the U. S. Senate, Senator Dennis Chavez—chairman of the Committee—addressed a letter to Thomas H. McDonald, Commissioner, Public Roads Administration, requesting that a study be made to determine the present status and future needs of rural local roads. He indicated that in consideration of S. 244 and S. 1471 it was evident that basic data concerning the present condition and future requirements of rural local roads was needed.

Senator Chavez requested that the report on this subject be submitted to the Public Works Committee by January 1, 1950 in order that it might be considered in conjunction with regular federal aid which is expected to be taken up by the next regular session of Congress.

At the hearings on the above mentioned bills testimony presented by the Engineer-Director of the American Road Builders' Association referred to the need for such a study as follows:

> "The practical step to be taken is to have a study and report covering the local road program and how it converges with the other systems. This report could cover traffic demands, standards of construction, means of financing and other factors that would have to do with the program.
>
> "The report could be completed in time for the next Congress when the next fedral-aid legislation will be considered.
>
> "Local roads are an important segment of the wealth and prosperity of this nation. It is therefore vital that a complete study be made with the view of establishing them in their proper place in our national transportation system."

Senator Chavez also stated that the Committee on Public Works will continue its study of the rural local roads problem and bills S. 244 and S. 1471.

Appraisal of the Adequacy of the Present Rate of Highway Construction[1]

By J. S. BRIGHT

Deputy Commissioner
Public Roads Administration
Washington, D. C.

HIGHWAY transportation is a cooperative enterprise in which the people, through government, furnish the roadbed, and private individuals furnish the rolling stock. Private enterprise has invested untold additional millions in facilities for distributing, replacing, and servicing the rolling stock. This transportation team serves as a link between our isolated resources of mining, petroleum, forestry, agriculture, industry, the centers of commerce, our national defense system, and in the development of our cultural, educational, and spiritual life. A glance at the map indicates how highways meet these problems and strikingly suggests the void that would be created if present systems of roadways were suddenly removed.

It is the purpose here to appraise the adequacy of the rate of highway production to meet the rolling stock needs. There are two aspects to the subject: Are we producing highways fast enough to sustain a transportation system to efficiently serve and promote the economy and welfare of the nation; and are we producing highways fast enough for timely completion of current authorized programs?

THE ADEQUACY OF THE RATE OF CONSTRUCTION TO SUSTAIN AN EFFICIENT HIGHWAY TRANSPORTATION SYSTEM

History of Accumulating Highway Deficiencies

It is evident to any motorist that many of our highways are now old, inadequate or worn out. Highways wear out just like a suit of clothes. There is continuous deterioration due to wear and tear of traffic and action of the elements. This deterioration is most noticeable in the road surfaces, but it is also taking place in the subgrade and structures.

Highways also become outgrown, just as clothes do when the wearer happens to be a growing boy. In a period when motor-vehicle traffic has been developing as rapidly as in the last 30 years, obsolescence becomes a greater factor on some roads than deterioration. Narrow pavements and hazardous shoulders are an outstanding example. Unfortunately, highway facilities cannot be junked or traded in on later models every few years as is done with motor vehicles.

Few people in the early 20's could foresee the rapid growth in traffic volume, the higher average speeds and the greater average weights which have developed since that time. Neither could they foresee the changing of the motorist's sight distance as car designs and car seats moved closer to the pavement and lowered the driver's height of eye. Even if these changes could have been foreseen, it would not have been expedient to make improvements too far in advance of the needs then existing, nor would it have been wise to concentrate too much of the available funds on a small mileage of highways.

It might be further noted that improvements made a quarter of a century ago, and now obsolete because of traffic growth, have long since paid for themselves.

Deficiencies have been accumulating on our highways and streets since the depression when state and local expenditures for highway reconstruction and expansion were slashed to the bone. During that period, it was not possible to keep pace with deterioration. Expansion of highway capacities, in order to meet the ever-increasing demand placed upon them by the motor vehicle (improvements of such vehicles being actually stimulated by the depression) was out of the question. During the war, that situation could not be physically corrected because of scarcities of manpower and materials. It was, in fact, aggravated by the increase in axle loadings permitted to meet the war emergency, and by the less than normal highway maintenance program that was possible under the nation's wide shortage of manpower, materials and equipment.

Obstacles in the way of rapid correction of highway deficiencies after "V-J Day" were reared by factors emerging from a nation converting from a wartime to a peacetime economy. Programs had to

[1] Presented at the American Road Builders' Association Meeting, Savannah, Georgia, May 13, 1949.

be altered to meet the everchanging condition of the construction market. Steel structures had to be partially deferred. Only the simplest type of highway work could be advanced.

Losses Resulting From Highway Deficiencies

A recent estimate published by the Brookings Institute indicates that the 1948 highway transportation bill was 30 billion dollars. About one-tenth or three billion went for highways. The other nine-tenths of the total went for automobiles, insurance premiums, gasoline, parking, lubrication, tires, and all the other products provided by priviate industry. A better public understanding of the ratio between the cost of highways and the cost of highway transportation would perhaps disclose that what appears to be a saving by restricting highway expenditures is being lost through excessive vehicle operating costs resulting from an overly conservative highway program.

It should be remembered that current physical deficiencies are merely the visible symbols of continuous economic loss. The loss itself, compounded as deficiencies increase, is in terms of accidents, time delays, parking problems, wear and tear on motor vehicles and all the attendant burdens placed upon the general economy. The most common visible evidence of deficiencies is the congestion through which almost every motorist struggles during peak traffic hours or peak days. The average speed in downtown business districts often drops lower than 10 miles per hour. Maintenance expenditures alone on state, county and municipal highways rose from 393 million dollars in 1921 to 1132 million in 1948. We pay for our highways whether we have them or not.

Estimates of Highway Deficiencies and Program Needs

The Economic Report of the President, transmitted to the Congress in January 1949, recognized current highway problems in the following words:

> "Highway traffic has increased faster than total production, population growth, or highway capacity. An annual 3 per cent increase in output and transportation would require an annual expenditure of at least 4 billion dollars for maintenance, repair, and new construction of our road system. About one-third of this should be assigned to city streets and expressways, one-third to primary rural roads, and one-third to secondary and local roads. Expenditures in 1949, including maintenance and repair, are not expected to equal even half our annual long-run needs."

Deducting the current annual maintenance expenditure from the 4 billion dollars would mean an annual construction program of 2.9 billion dollars. It is double the $1,569,000,000 of all state, county, city and local highway construction work performed in 1948.

Accumulated highway deficiencies by far exceed either of the above amounts. This fact is disclosed by the state-wide highway needs surveys made at the request of state legislatures or the executive departments of state governments. The surveys were made by experienced engineers who determined the deficiencies by a mile-by-mile appraisal of each road and street, using standards or yardsticks of measurement approved by state, county, and city engineering committees. This inventory of deficiencies represents the very core of highway problems. It presents, categorically, the accumulated backlog of new construction, resurfacing and widening, weak or narrow structures, realignment, and other major improvements necessary to render adequate service to highway traffic. Surveys in the eight States of California, Illinois, Kansas, Michigan, New Hampshire, Oregon, Vermont and Washington disclosed that this group alone had highway deficiencies which need immediate correction in the amount of $6,627,000,000. California called these "critical deficiencies"; Oregon, "immediate construction needs"; and the Illinois report had this to say:

> "By far the most serious aspect of the present highway problem is this accumulated deficiency in all systems. The fact that about $2,518,916,800 is needed right now to correct existing highway deficiencies is alarming."

An even more specific example of highway problems is furnished by Arkansas, one of the group of southeastern states. The Eighteenth Biennial Report of the State Highway Commission has this to say:

> "Arkansas has not had a road life study program in the past and does not know at what rates the roads are wearing out or need replacement due to obsolescence. However, based on national averages, it can reasonably be expected to lose within the next ten years thirty-seven per cent of the high type pavements, sixty-one per cent of the blacktop roads and eighty-nine per cent of the gravel and crushed stone surfacing. To replace these losses, under current standards and at present prices, would require $15,000,000 annually. Against this need, the financing during the biennium, including federal aid, has provided an $8,000,000 to $10,000,000 annual program."

The Commissioner of Public Roads in testimony before Congress on the 1948 Highway Act indicated

that based on road life study charts the annual surface replacement needs on the 611,226 miles of federal-aid primary and secondary systems would probably be 40,000 miles per year. It was comprised of about 13,100 miles on the primary system and the remainder on the secondary system. In 1948 20,510

HIGHWAY NEEDS

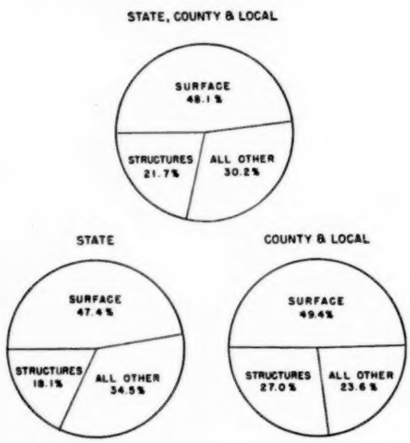

CHART I

miles of federal-aid primary and secondary highways were actually constructed under authorized programs. The Commissioner's reference was made to annual surface replacement needs. The accumulated deficiencies both on and outside the surface are even greater.

Surveys of state, county and city highway systems in 17 states (including the above-listed 8 states) disclose that 579,010 miles, or 49 per cent of the 1,172,785 miles of highways appraised, are deficient. The estimated cost of correcting these deficiencies over a 10-year period is $16,600,573,353. Within these amounts, 102,471 or 55 per cent of the state highway mileage was deficient and would cost 10.4 billion dollars to correct; 447,359 miles or 49 per cent of the county and local mileage would need correction at an estimated cost of 3.2 billion; and 29,180 miles or 41 per cent of the city streets would need correction at an estimated cost of 3 billion dollars.

The per cent of accumulated state highway deficiencies checks with the findings made on the primary federal-aid system in ten states principally located in the west. The Public Roads Administration in 1948 under a newly developed maintenance inspection technique rated on the basis of a 100 par the "condition," "safety," and "service" characteristics of 36,279 miles of federal-aid primary highways:

Condition was evaluated from the standpoint of *anticipated life, maintenance economy,* and *structural adequacy.*

Safety was measured in *widths of elements, sight distances,* and *consistency of alignment.*

Service was rated on *dispatch, ease, economy,* and *direction.*

18,709 miles were below the tolerable rating of 70 on either one of the elements of condition, safety or service or on a combination of these elements. This is a 52 per cent accumulated deficiency in some phase of the mileage.

State surveys of highways deficient on part of the remaining 2,081,215 miles of highways and streets in the country are being made in some of the states. If the pattern of highway deficiencies disclosed in the 17 states surveyed holds true in the remainder of the 48 states, the estimated cost of correcting all the highway deficiencies over a period of 10 years would be at least 47 billion dollars.

In comparing the deficiencies and estimated expenditures needed for their correction, it is to be remembered that while only 10 per cent of the nation's mileage are primary state highways, they carry 38 per cent of all traffic; 81 per cent, which are secondary and local roads, carry 12 per cent of the traffic; and 9 per cent, which are city streets, carry 50 per cent of the traffic.

Nature of Highway Deficiencies

At this point it may also be of value to the highway industry to have a general idea of the nature of the work that will be needed to correct highway deficiencies so that equipment production, acquisition and contractors' organizations and capacity can be geared or slanted to the work ahead. From the items of work listed in the reports of state-wide highway needs studies, it is disclosed that 48.1 per cent of the combined state, county and local needs are on the surface; 21.7 per cent, structures; and 30.2 per cent, all other items. The following is a further breakdown of the work for state and local highways. It is also illustrated in Chart I.

Classes of Highways	Surface, per cent	Structures, per cent	All Others, per cent	Total, per cent
State	47.4	18.1	34.5	100
County and local	49.4	27.0	23.6	100

Inadequate Highway Construction Rate in Relation to Expanding Commercial Vehicle Registrations, Overweights, and Ton-Miles Hauled

State-wide highway needs surveys are not the only clarions calling attention to existing highway problems. Records of motor-vehicle registrations and of expanding highway use are self-explicit. Motor-vehicle registrations rose from 10,493,666 in 1921 to 41,151,326 in 1948; the latter figure includes 7,555,330 trucks. Motor-vehicle travel expanded from 55 billion vehicle-miles in 1921 to 395 billion vehicle-miles in 1948. The frequency with which your car at higher modern speeds passes a truck on an obsolete 18-ft. paved width may be reflected by the fact that in 1904 the ratio of trucks and busses to passenger cars was 1 to 78; by 1910 this ratio had become 1 to 45; in 1920, 1 to 7.3; in 1930, 1 to 6.5; in 1940, 1 to 5.9; and in 1948 it was a ratio of 1 truck and bus to 4.5 passenger cars.

The frequency with which overweight trucks are deteriorating pavements is also to be noted. From counts made in Illinois at loadometer stations during the period of investigation, the total yearly occurrence of tractor-semitrailer and truck-and-trailer types of combinations on roads at these locations was determined to have been 3,016,260 in 1945 and 3,361,285 in 1946. Of these totals 11.5 per cent, or 346,870 units, exceeded the 18,000-lb. limit in 1945; and 15.5 per cent, or 521,000 units, exceeded the 18,000-lb. limit in 1946. The overload occurrences were determined only for loadometer station locations and were not projected to an estimate of occurrences throughout the state.

Another indication of the insufficiency of the present rate of highway improvement is the need for load restrictions during the spring break-up. These load restrictions are needed to protect road surfaces from destruction and to keep roads passable and in reasonably good condition for travel by all but the largest loads.

As an illustration, in the spring of 1948 a total of 7,638 miles of trunk highways were restricted in Minnesota to axle loads below normal legal limits.

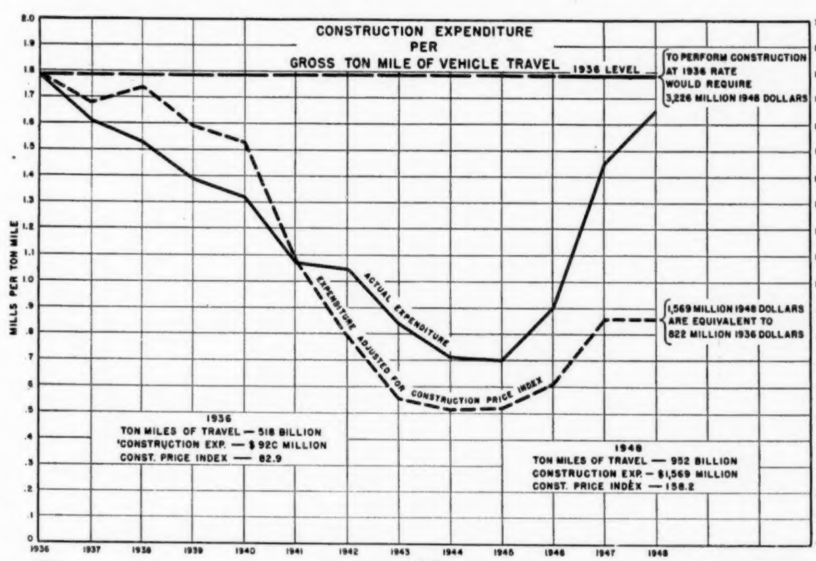

CHART II

The number of miles posted for various axle loads was as follows:

Maximum Axle Load, tons	Miles Posted
1.5	9
3	1,822
4	3,313
5	1,900
6	245
7	349
Total	7,638

The restricted mileage represented 68 per cent of the total trunk highway mileage. The restrictions were in effect for varying periods from early March to June 10, averaging about 6 weeks.

From the foregoing, it seems evident that the annual rate of construction has not kept pace with the expansion of ton-mile movement over the highways. It would be interesting to observe the extent of this lag in relation to ton-miles of traffic. Converting passenger and commercial vehicle-miles traveled into ton-miles and relating it to annual construction expenditures, it will be found that in 1948 only one-half as much highway construction was put in place as in 1936. (Chart II)

In 1936 this nation expended 920 million dollars on the construction of highways. In the same year it is estimated that 518 billion ton-miles of vehicles moved over the nation's roads. There was then being expended 1.8 mills of construction money for each gross ton of traffic moving one mile. Last year

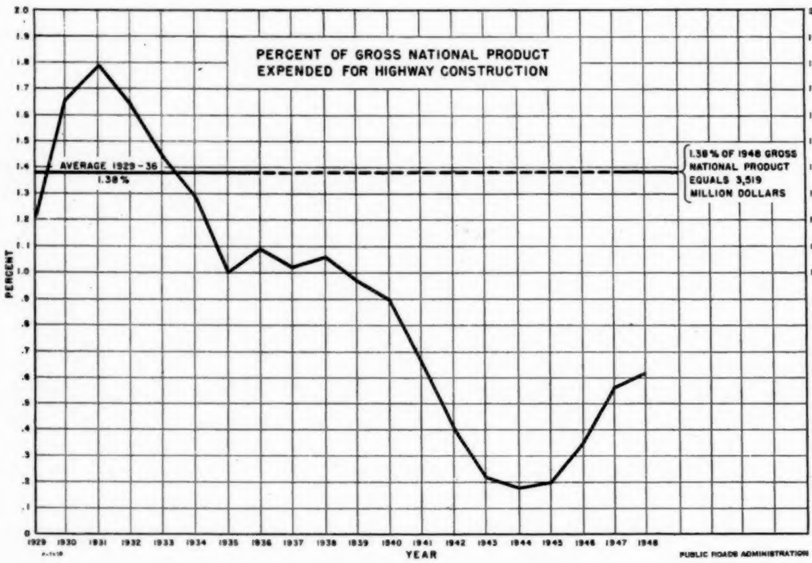

CHART III

1569 million 1948 dollars were expended for construction and an estimated 952 billion ton-miles of traffic moved on the highways. It amounted to 1.7 mills per ton-mile. But, the 1948 dollar bought less construction. In terms of 1936 dollars this was less than .9 of a mill. Therefore, in relation to the gross ton-miles of vehicle travel, only half as much construction was being performed in 1948 as in 1936.

Inadequate Highway Construction Rate in Relation to Business Trends

Passenger vehicle movement and truck hauling within legal size and weight limits are, of course, essential in supporting agriculture, industry, and our standards of living. Without transportation there would be little point in the farmer growing more than he could consume himself, and the factory, with its low-cost mass production techniques, must have millions of customers. It will be well to reflect on how the highways are used in the business of the day.

Motor trucks in winter carry the major part of Florida products, principally fresh fruits and vegetables, to markets within 700 miles, with heavy tonnages going as far north as Philadelphia and New York. In Texas, Arkansas, Alabama, Mississippi, Tennessee, Georgia, and the Carolinas, you will pass the big, flat semitrailers carrying baled cotton. Successful mass production of automobiles in Michigan is dependent on uninterrupted flow of materials. The gray-green auto body must arrive at the assembly line at the precise moment that the chassis with gray-green wheels is ready for body installation. The reliance on highway transportation is heavy in the assembly plant processes. Space limitations make it impossible to store enough parts to feed production lines for more than a few hours or a few days. The automobile makers, therefore, use the rolling truck itself as a warehouse and reduce inventory and handling costs.

Small business has equally integrated the use of the highway in daily operations. The corner grocery store, which formerly bought in large quantities because of the length of time it took to receive shipments, can now operate on much smaller inventories because of the frequent delivery of merchandise.

These are but a few reflections of how highways are used in business. How did highway production keep up with the business trend? (Chart III) Some indication may be obtained by comparison with the gross national product. It fluctuated during 1929-1936 but, using the average as a base, highway construction expenditures were 1.4 per cent of the gross national product. In 1938 they were 1.1 per cent; in 1940 they were .9 of 1 per cent; in 1942, .4 of 1 per cent; in 1944 they were at a low of .2 of 1 per cent; but by 1948 they were back up to .6 of 1 per cent. In 1948 the gross national product was 255 billion dollars, and highway construction expenditures were 1 billion 569 million dollars. The 1948 ratio of .6 of 1 per cent again discloses that the rate of highway production would have to be doubled to approach the 1929-1936 highway construction rate of 1.4 per cent of the gross national product.

Inadequate Construction Rate in Relation to Rate of New Motor-Vehicle Acquisition

As a last analysis, a comparison has been made of the annual construction expenditure with the expenditure of the transportation partner in the purchase of new rolling stock. (Chart IV) In the period 1926-1936 highway construction expenditures averaged 62 per cent of expenditures for new motor-vehicles. This ratio fluctuated downward until the period 1946-1948 when the highway construction expenditures amounted to 27 per cent of expenditures for new motor-vehicle purchases. Here again is shown the fact that highway construction is lagging at least 50 per cent behind the rate of new rolling stock acquisition.

Restatement

It has thus been shown that the Economic Report of the President, transmitted to the Congress in January 1949, indicates that the rate of highway construction expenditures should be double the 1948 rate to meet highway transportation needs. Statewide highway needs surveys and field inspections disclose that actual accumulated highway deficiencies by far exceed this amount. It has also indicated that the 1948 rate of highway construction should be at least doubled to keep up with the ton-mile movement over the highways, the business being handled on the highway as reflected by the gross national product, and with the rate at which new rolling stock is being acquired by the private partners of the highway transportation team.

Report of Deficiencies of the Major Routes to Serve the National Defense

Very shortly, the Public Works Committees of the Congress will have before them a detailed report on the substandard conditions of the interstate highways and other major routes which are essential to national security and national defense. This report is based upon the detailed studies by the state highway departments. The Secretary of Defense and the National Security Resources Board have cooperated fully. The report was directed by the Congress in the 1948 Highway Act following the precedent of 1941. The report at that time on "Highways for the National Defense" resulted in special appropriations approximating 350 million dollars for the major routes and defense access roads.

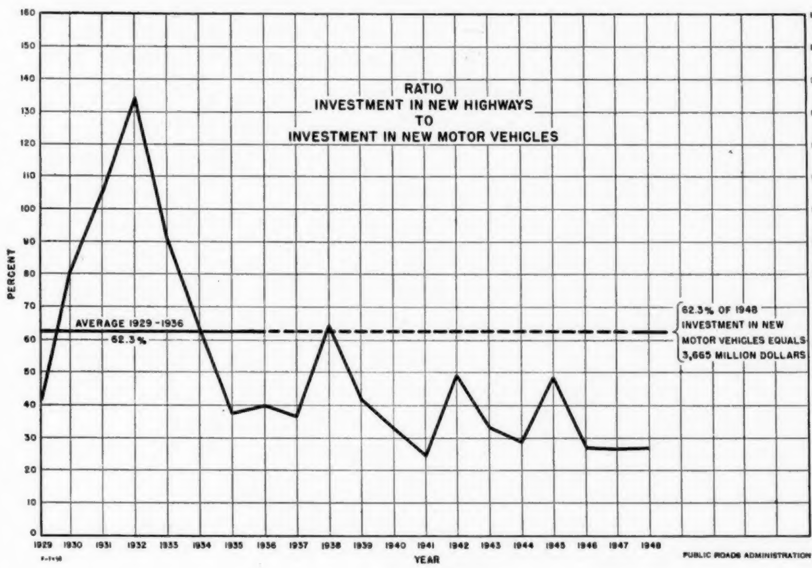

CHART IV

The final figures of cost for bringing the Interstate Highway System and other necessary roads to a state of reasonable adequacy for the national defense, as of the present, will total in excess of 10 billion dollars.

THE ADEQUACY OF THE RATE OF CONSTRUCTION TO MEET AUTHORIZED PROGRAMS

There remains a review of the progress being made in the production of highways for the timely completion of current authorized programs.

Notwithstanding the delays and problems of the postwar years, there is now much promise for the future in the road contracting field. The Federal-Aid Highway Act of 1944 greatly broadens the base for contract construction between the wide extremes of the simplest, least expensive types for low traffic volume farm-to-market road, to the urban arterial type for the daily use of many thousands of vehicles in the metropolitan area. The three systems—federal-aid primary, federal-aid secondary and urban arterial, as now definitely selected, total 611,226 miles.

The postwar program set in motion by the Congress in October of 1945, while apparently slow in getting under way, now extends to more than 70,000 miles in all stages, of which 37,529 miles of all classes and types have been completed.

Measured in terms of dollar value of construction put in place, the federal-state cooperative highway construction has accelerated steadily since the end of the war period. From approximately 90 million dollars total cost in the calendar year 1945, advances to 329 million dollars in 1946, 580 million dollars in 1947, and 768 million dollars in 1948 have been recorded.

It appears likely that during the present calendar year, federal-aid construction put in place may reach values of 850 million dollars in total cost and 440 million dollars in federal funds. This is about equal to the annual rate of federal fund authorizations carried in the Federal-Aid Highway Act of 1948.

The momentum gained in more than three years of postwar highway production, in spite of the numerous handicaps encountered attest to the resourcefulness and vitality of the contracting industry, the state highway departments, and the highway officials of local governments, both rural and urban. A large program also requires an army of workers, trained for their jobs and equipped with a large array of tools and machines. Such an army cannot be created in a period of months. To function most cheaply it must be kept busy throughout each working season.

Equipment Shortage Fading

The shortage of highway construction equipment seems to have largely disappeared, at least from the manufacturer's and distributor's standpoint. There may perhaps be some lag on the part of the contractors in replacing old equipment or taking on new types. This can be due, to a large extent, to present prices. The reluctance of distributors to enter into a buyer's market, which perhaps means cutting distribution profits by making higher trade-in allowances, may also influence users' purchases.

Any lack of confidence that the highway contractor may have in the continuance of an adequate highway program will, of course, also affect his equipment purchases.

Trend in Highway Construction Bid Prices

It is also apparent from work let to contract during the first quarter of the calendar year 1949 that a decided break has occurred in the upward price trend.

Out of approximately $118,000,000 of contract awards, there has been a decline of 2.4 per cent in the composite mile index from the previous quarter. Structures which had been the principal contributing element in past upward trends show a 5.1-per cent decline. It is comprised of the following three elements which have individually declined as follows: Structural steel, 1.2 per cent; reinforcing steel, 2.6 per cent; structural concrete, 7.3 per cent.

Common excavation remains the same as in the last quarter of 1948. The last quarter of 1948, however, showed a drop of 4.5 per cent from the third quarter. Concrete pavement has dropped 2.3 per cent since the beginning of this year.

Contractors' Capacity

There have been differences of opinion over the capacity of the contracting industry to handle the postwar federal-aid construction program.

Field engineers of the Public Roads Administration in recent reports indicate, in general, that the situation is quite satisfactory. Increased competitive bidding is pronounced. Twenty-four bids were received on one project in the first quarter of 1949. No less than 15 bids have been received on several projects in various parts of the country. On this sample the aggregate of bids was 19 per cent less than the engineers' estimates but for the entire federal-aid program for the calendar year 1948, the total low bids were only 1.8 per cent below the engineers' estimate; however, for the first quarter of 1949 the low bids were 6.5 per cent below the engineers' estimate which would indicate that lower bids are being received during 1949.

The improved condition is attributed to a decrease in contractual uncertainties, the establishing of long-range programs and the influx of new contractors. Of the total 2039 contractors receiving 1948 awards, there were 562 new contractors. In addition to the new successful bidders, some 500 new potential contractors were unsuccessful. It is significant that of the contractors in 1947 obtaining awards, 913 were not successful in 1948. From this you can draw your own conclusion. As previously indicated, there is a marked increase in competition. In 1946 the average number of bids for the entire country was 3.9 per project; in 1947 it was 3.8 bids; and in 1948 it increased to an average of 4.2 bids per project. A marked rise has occurred in the first quarter of 1949 to 5.9 bids per project.

While the reports are favorable on a national scale, in several states it is questionable whether the local

contractors have sufficient capacity to carry on the size of program necessary to fully utilize the federal-aid funds as they become available. In states where such capacity is lacking, neighboring areas have ample or surplus capacity to supplement the needs by proper promotion. It may be the highway department's fault if out-of-state contractors do not bid.

Engineering

The lack of sufficient engineers to properly carry on the survey, design and construction has been a serious stumbling block to the successful execution of the postwar federal-aid program in many states. The causes are basically the same wherever they occur: loss of personnel during the war period, inability to recruit and hold the necessary additional engineers because of relatively low salaries, insecurity of employment, poor prospects for advancement, inadequate subsistence allowances, undesirable working locations, frequent moves from place to place and seasonal nature of work.

Legislative action is generally required to improve the situation, and legislatures now in session are considering the problem in most states. Other measures for improving highway employment include in-service training programs, publicizing and recruiting campaigns, scholarships and special training courses.

Some states have apparently let their backlog of plans become depleted to the extent that it will be an obstacle to stepping up a larger highway program. The employment of consulting engineers has aggravated the situation due to competition for the available supply. Secondary programs dependent on county organizations have also run into a major shortage of personnel. Bridge engineers are a class especially scarce.

Surveys of colleges indicate that twice as many new highway enginers may be available in 1949 as in the previous year. This is not too encouraging when considering the enlarged highway needs ahead and the fact that the Federal-Aid Act is now in effect close to 30 years and engineers who worked in the initial stages of the program are approaching retirement.

North Carolina State College, School of Engineering, at Raleigh announces that next year they will offer a course in which the curriculum will lead to the degree of Bachelor of Science in Construction. The program of study will integrate engineering administration, job management, labor relations and construction methods and practices.

It is my opinion that such a course is long overdue. There has always been a large field, especially in the construction and maintenance division of state and county highway departments, where men are needed with practical training and not stratospheric flights in design. In fact, there are many types of minds which would be successful in construction and maintenance that would not be adapted to the orthodox courses offered in some engineering schools. This should be a mutual field of interest for the construction industry and the highway departments jointly with the universities to develop courses that would furnish an adequate supply of construction and maintenance engineers so that progress in our highway programs can be achieved.

SUMMARY

Summing up the foregoing points of interest the facts develop that the construction program has reached a volume contemplated in the postwar highway legislation. This volume is not sufficient to satisfy present needs of postwar highway transportation. The construction industry can undoubtedly step-up production to handle a larger volume of highway construction.

The annual highway programs, both federal and non-federal-aid, should be stepped-up or increased to a point where reconstruction, betterments and new construction overcome accumulated deficiencies. Thereafter a program for the replacement of annual depreciation and highway obsoletism would be adequate. The extent of additional funds necessary to carry on such an enlarged program is problematical, depending upon stabilization of prices, and the contractors, material suppliers, and equipment manufacturers' ability to respond to such demands. In order that the construction industry be properly geared to the work ahead they should be given a firm long-range program, say from five to ten years, in sufficient detail as to the types, location, and timing of projects. It is conceivable with the leveling-off of prices, improvement of machinery, organization, and administration, that the present source of funds in some states that have put their finances in order may be sufficient to furnish the necessary finances without resorting to debt obligations against future revenues. Other states must take stock of the highway problem and put their houses in order. In other words, we need more long-time planning and teamwork.

Why A Safety Program?[1]

By MERVYN G. GASKIN

President
Taylor & Gaskin
Detroit, Mich.

WE ASK the question, "Why a safety program?" and we give you our answer right at the start. A safety program pays big dividends to all of us in cash and in a clear conscience. Aside from causing needless human suffering, accidents cost money, lost pay, and economic waste. We can estimate direct financial loss from accidents but not their full effect on human health, happiness, and the standards of living.

Apart from this, however, we have a very selfish answer—"It pays." It pays in the lower cost of insurance, which is a part of our overhead. It pays in the preservation of our machinery and equipment; none of us wants to ruin a $25,000 crane or similar equipment. It pays because we are able to get more and better work and a better class of men, for they know we have their interests at heart . . . we are trying to protect their lives every minute of the day.

The first thing we tell our men is that if they are going to work on our job, they have to work safely and think safety. That was our motto last year, "Blueprint for Safety—Work Safely, Think Safety." It pays in our relations with our customers, as they know that we are not only trying to protect our own men, but their employees and their property as well.

A year and half ago our company was sued for a half million dollars on a fire loss. We won, as we showed that we had done everything in our power to protect the property of the owner. We had done this through a program of instruction in fire prevention to our foremen. If we had lost this case, it would have ruined our company. That might happen to many a company.

Contractors are resourceful. If they have a problem, they lick it immediately. There is no set formula. No two jobs are alike. Why not apply the same principles to accident prevention? You wouldn't postpone for very long an important decision on a matter even minutely affecting the cost of your job. One contractor told us they have meetings every week in which they check their costs to see how they are making out, and if any one part of the job is going haywire, they immediately plug the leak. Why, then, shouldn't we do the same thing in accident prevention?

As the beloved Al Smith used to say, "Let's look at the record." We are going to talk about frequency rates and severity rates. The frequency rate is the number of disabling injuries per million man-hours of exposure. The severity rate is the number of days lost per 1000 man-hours of exposure, including charges for permanent disabilities and deaths.

According to figures published in the 1948 edition of *Accident Facts* of the National Safety Council, steel erection has a higher frequency and severity rate than mining, with the exception of anthracite mining, and even when compared with anthracite mining, steel erection has a higher severity rate.

In 1947 the construction industry was 34th out of 40 in severity rating. Approximately 150,000 men were disabled, 2400 of these workers died, and about 4600 were left some form of permanent physical impairment. This means that one out of 16 suffered an injury and three out of every 1000 were either killed or suffered permanent disability.

Let me quote from the March, 1948, issue of *Construction*, a publication of the United States Department of Labor, Bureau of Labor Statistics:

"The humanitarian and social implications presented by this large volume of injuries are immeasurable. From the economic viewpoint alone, however, it is clear that these injuries constitute a very large expense item which must be absorbed by the industry. The actual time lost by construction workers in 1947 because of work injuries experienced in that year is estimated as about 3,300,000 man-days. On this basis of current average hourly earnings for construction workers, this would represent a direct loss of $46,200,000 in wages alone.

"The time lost in 1947, however, does not adequately measure the real loss resulting from these injuries. Many of the seriously injured workers will find their earning ability reduced for the remainder of their lives, and for those who were killed, the loss is equivalent to their entire expected earnings during the years to come when they would have been working if their careers had not been cut short by premature death.

[1] Condensed from an address before the Annual Meeting of the Associated General Contractors of America, New York, March 2, 1949; reprinted from *National Safety News*, May 1949.

"If additional allowance is made for the future effects of the deaths and permanent impairments included in the total, the economic time loss chargeable to the injuries experienced in 1947 would amount to about 24,100,000 man-days. At current earning levels this would represent a loss of $337,000,000 in present and future earnings, all of which must be absorbed by the employers, the workers, their dependents, and the consumers.

"Historically, the construction industry has consistently had a high injury record."

Well, what can we do about it?

Evidently a great deal, if we would do it. Again according to *Accident Facts,* the best no-injury record in the construction field was a job of the Du Pont Company at Belle, W. Va., with 3,582,134 man-hours worked without a disabling injury. We find this same company holds the record in the textile industry, the chemical industry, and iron and steel products. Evidently Du Pont knows how to prevent accidents in any field. The answer is simple. They have a safety program. They find it pays; they practice safety and they make the contractor practice it.

We all know that in the majority of cases, the large jobs have a better safety record than the smaller ones, for the simple reason that there are safety engineers watching these jobs.

One general contractor with jobs in 14 locations shows 423,800 man-hours worked, with one disabling injury—ten per cent of the national average frequency. We notice also a job well done by the Constructors Association of Western Pennsylvania. In their December, 1948, *Bulletin,* it is stated that their compensation rates on roads and streets in 1935 was $7.00, and in 1948 it dropped to $2.38. It also contains a highly complimentary letter from the council of the union involved, pledging their full support in accident prevention. Local AGC Chapters in Detroit and Milwaukee are doing a good job.

Let's again refer to a statement in *Construction*:

"A high degree of hazard is admittedly present in construction work. Most construction hazards can be overcome, however, through application of safety principles. Fundamentally, the accident record of the construction industry is more indicative of inattention to safety principles than of the inherent hazards of the work.

"Evidence to support this conclusion is apparent in a comparison between the injury-frequency rates of private contractors engaged in work for the Corps of Engineers of the United States Army and of those engaged in non-federal work. The standard contract of work under the Corps of Engineers specifies that safety supervision must be provided, and the specifications for the work outline basic measures for controlling known accident hazards. Enforcement of these provisions by inspectors of the construction forces of the Corps of Engineers has consistently resulted in much lower injury-frequency rates for work under their jurisdiction, than has prevailed in other construction work."

These figures show that the work supervised by the Corps of Engineers was from 2 1/2 to 3 1/2 times better in accident frequency. Do you realize what this statement means? It registers but one thing in my mind, and that is legislation. In other words, if we don't do it the Department of Labor can show us how. This terrific waste of manpower cannot and should not go on.

The boys down in Washington are looking for a reason and an excuse. Sometimes they don't even need the reason. In this case, they don't need to look for the reason; we've given it to them.

Let's get back to our topic "Why a Safety Program?" Several years ago, we of the Steel and Metal Erectors Association of Michigan, of which I was then president, were alarmed about our compensation insurance rates, and the frequency and severity of our accidents. Our company was greatly interested, as we had to pay a rate set up by the Compensation Bureau, which as you know sets a rate in accordance with the experience rating of our industry in our state. In 1943 the Bureau rate for structural steel erection was $31.57 per $100 of payroll. Our company had a debit rating of 14 per cent so our rate was $36.

Some of our competitors, who were self-assured, did not pay these rates. They had definite safety programs and safety rules and regulations. They were using in that year a rate of approximately $7 against our $36 per $100 of payroll, an advantage of $29 per $100 of payroll over us. When overhead and profit were added, it meant a difference on the average steel erection job of $5 per ton. What chance did we have of competing against them? Something had to be done.

Our Association organized, through the Detroit Industrial Safety Council, affiliated with the National Safety Council, a series of dinner meetings, to which we invited management, supervisors, and all foremen engaged in steel erection in our area. We asked each company to pay the cost of the dinner for their representatives. We have specialists in their fields

address us on the use of equipment, safe ways to work, fire prevention, first aid, etc.

We conduct five meetings a year. We keep a record of attendance, and previous to each meeting we send a post card to the home reminding everyone of the meeting.

We discuss mutual problems. We stress the cost to our men in the possible loss of pay and from union assessments paid to their members due to accidents. Nothing but accident prevention is ever discussed. There is a definite yearning by our supervisory employees for information on accident prevention.

After an address, we have a discussion period, which is the most fruitful part of the meeting. Our men make suggestions and criticisms, sometimes with good natured kidding, as when one of our foremen appeared with a knot the size of a billiard ball on his head. We found he had been hit by a crane block and hadn't been wearing a hard hat. We have a committee to investigate serious accidents and act on suggestions. All serious accidents are reported and discussed at each meeting.

At our December meeting four serious accidents were discussed, two deaths, one permanent and one partial disability. Upon investigation we found that in each of these cases, the companies involved and the foremen on the job had never participated in any of our meetings. Naturally they were immediately invited. We have to pay for their accidents, because our insurance rates are set on the cost of *all* accidents.

The foreman holds a job meeting the day after our meeting, and explains to his gang what he has learned the previous night. Sometimes we suggest he hold weekly meetings for about 10 minutes on a Monday morning with some safety suggestions to the men. They inspect all equipment.

Our company sends to each foreman at his home a monthly report showing his experience, number of hours worked, accidents if any, total lost time, and cost, with some explanations and words of encouragement. Believe me, they watch these reports very carefully. No foreman wants his record marred.

The monetary results have been remarkable. The compensation rates for riveted steel erection in the State of Michigan have decreased from $31.57 in 1943 to $12.11 this year. They gave us the maximum allowable reduction of 25 per cent from last year. In other steel erection the reduction was from $15.62 in 1943 to $4.92 this year, and these rates will keep on going downward, as they are predicated on 1944 to 1946 experience.

The remarkable feature of these statistics is shown by the fact that in 1940 our total payroll was $166,400 with five serious accidents, 39 non-serious, with total losses of $46,461, as against 1946, when we had a payroll of $980,000, one serious loss, 32 non-serious, and total losses of $38,683, a 600 per cent increase in payroll and a 20 per cent reduction in losses. Remember, this is the worst portion of our industry, as the better employers are self-assured, and their payrolls and accidents are not included.

Our company had a 5 per cent credit on a base rate of $28.95 in 1944, and this year we have a credit of 42.1 per cent on a still lower base rate of $12.11, or a net rate of $7.01 for steel erection insurance as against $36.00 in 1943, a saving on every hundred dollars of payroll of $29. In 1947 we had a refund of $16,400, and in 1948 a refund of $18,700. The reduction in compensation rates for steel erection means a savings to our industry in Michigan on a payroll of approximately $3,000,000 or $583,800. This is a part of what we have accomplished through our program in a period of four years.

We think these results are really worth all the time and effort we have expended. Our men are safety conscious, and we are determined to keep them that way, but we of the local structural steel industry cannot do the job alone.

Our own section of the construction industry together with all other segments of the industry must do a similar job to produce a better safety record for the industry as a whole. This must be done through our cooperative efforts because in the construction industry men work for one contractor today, and another tomorrow. In other words, one company in one locality cannot do the job alone. It is an industry problem; otherwise we will be forced into a program through legislation, restrictive measures, and safety codes arising from sources over which we have little or no control.

You may think this an idle threat, but we need only consider what has happened in social legislation in the past few years. We may be told what types of scaffolds to use, from whom we shall buy our equipment, how many men we shall use on a piece of equipment and how many men it requires to do a job. It is of little use having just one section of the industry safety conscious. We know in our own industry that a great many serious accidents could have been avoided if other trades had worked with us in accident prevention.

We know of a case of a bricklayer who was totally and permanently disabled. He had been told not to

work around our steel erection, but the foreman told him the job had to be done, to go ahead and do it. He was hit on the head by a piece of steel, lost a part of his brain.

A steel erector was disabled because of the faulty setting of anchor bolts. A contractor thought it was easier to cut off the anchor bolts and pour concrete around them after they had forgotten to set the bolts than to knock the concrete out and pour new footings with the proper bolts.

During 1948 in one automobile plant in Detroit there were four steel erectors killed. In every case we found that these deaths could have been prevented. In one case the widow sued the company for $100,000. It was settled out of court for $35,000. This can happen to anyone of us, and it may mean the difference between a profitable year and a very unprofitable year.

We argue a great deal with our employees about giving them a nickel or dime increase per hour. Here in the case of steel erection we have shown you a saving of 20 per cent in insurance rates, which means 50 cents per hour. It makes no difference whether it is in the man's wages or insurance, it is still a part of the cost of the job.

In one state, payroll for carpentry alone was $90,000,000. If we made a saving of 10 cents per $100 on insurance, it would mean $90,000. One contractor told us his total payroll in 1948 was over $10,000,000, so at that rate he'd save $10,000.

However, let us not be under any delusion that our premium rates have been lowered solely because of accident prevention. We have two contributing factors—increased payrolls and full employment. A man preferred to work for $125 a week rather than be on compensation at $21 and we were glad to let him work. Conditions are changing rapidly, and rather than be unemployed, he'll be on compensation.

We need more effective control over our serious injuries. That is one of our industry's present problems. We can't sell safety by posting bulletins and posters at the job site. It may help, but we've got to do more than that.

First, management must be sold 100 per cent on safety. There is an old saying, "It is more important to know what kind of patient has a disease than what kind of disease a patient has."

We study and become expert in all phases of safety and every aspect of the safety problem except the one which is common to every serious accident—the human being in the accident. There is always a man in the picture. Well that is only the symptom, not the disease. The disease is that we of management didn't recognize this is a personal problem.

One of our greatest hazards is haphazard supervision. We have taken a great deal out of the hands of our foremen, but he still has the most important job in the world—that of dealing in human relations. Therefore, we should plan our safety program as a part of human relations, not a general program, but one that will appeal to each man directly and specifically.

General Motors decided they could not get enough individuals to talk safety to all their men, so they used the idea that every supervisor, every day without fail, must talk to two people individually about safety. He must keep a record of the person to whom he talked, and what he talked about. Take a minute or five minutes or one-half hour if necessary. No big meetings. No general stuff. It is strictly personal, and they get real teamwork from that kind of individual work. Like a football team. Everyone is taught general principles, but in addition the line men are taught, the kickers are taught, the passers are taught. In the same way the continuing and abiding principles of safety should be taught to everybody.

But every man must be taught. We should talk to every man and educate him and train him in terms of safety as it relates to him, to safety in his specific job, and operation, and safety as it refers to him.

A crowd can be rowdy and hard to handle, but get one man apart and he is a totally different person. We can teach safety in groups, but we must teach men individually.

We must recognize that although safety is a monetary concern to us, it is of more serious concern to the worker. It concerns his life, his home, and his whole future.

It is management's prerogative to recognize safety in the worker's program, in which management will cooperate by offering complete financial and technical help. Safety is a worker's problem, financially, emotionally, physically, and socially. It is our problem only financially. We've got to sell our program to our workers.

We must show genuine enthusiasm. Supervisors must be enthusiastic. Today we do not think a superintendent or foreman who does not have enthusiasm for accident prevention is fully qualified for his job. Intelligent concern for the welfare of the workers is one of the chief additions to requirements.

He must feel his personal responsibility, and the company's responsibility to its people.

A safety program is not something we can start and stop. It must be continuous, day after day, week after week, month after month. Sometimes it is very discouraging. We know of one contractor in Detroit who worked 18 months without a serious accident, and all of a sudden had three fatalities in three weeks. This didn't discourage them. They determined that something was haywire somewhere, and plugged the gap.

Recently this same contractor, on the Detroit Edison job, insisted on 100 per cent hard hat coverage. If you didn't wear a hard hat, you couldn't work on the job. And that applied to everyone, subcontractors, engineers, and supervision. The owners accepted the program and their men cooperated 100 per cent. Four probable fatalities, and five serious accidents were prevented. This meant a saving of about $95,000 in insurance costs.

It is my personal conviction that a planned safety program, incorporating the three E's, education, engineering, and enforcement, followed by a thorough training, with sustained follow-up, should be carried on by all sections of our industry. It should be directed by your association and the local chapters, and it should have your fullest cooperation. It has been definitely a profitable undertaking for us, and we feel certain that you can obtain as good or even better results.

As we pointed out previously, if we don't do it, someone will do it for us. We have licked bigger jobs than this, let's lick this one too.

The U. S. Corps of Engineers Approach to More Durable Concrete

(*Continued from Page 10*)

These three things that I have mentioned relative to durability of mass concrete structures have been partially overcome by the use of air-entrained concrete. It has done its part, but as I mentioned earlier, we cannot expect air entrainment to do everything. If air entrainment with normal gradation of aggregates, normal uniformity, and normal particle shape, will permit us to cut the cement content down, the water content down, and the fine aggregate content down, all of which we must do to place good, durable, impervious mass concrete, then the improved uniformity, gradation, and particle shape of the fine aggregate particularly, will permit us to do the rest of the job.

I have stressed mass concrete dams because primarily I am interested in mass concrete dams. Building structures by the use of ice to cool the concrete temperatures, or by the method of cooling the aggregates down to 35 F. by inundation for the coarse material and the use of "dry cooling" the sand, or by cooling the aggregates by the use of air alone—these are all intriguing to me. We place mass concrete in hot weather limited to 60 F. and sometimes lower as it goes into the forms, all of which is for the purpose of promoting durable concrete. If we do these things, it has been my contention that it is logical to assume we would be willing to spend money for durable aggregate and to pay for quality of materials as well as the gradation, particle shape, and uniformity of the materials throughout the job.

We do, however, recognize the economic importance of relaxing such gradation specifications for minor work, and we are doing just that. On many of our jobs that are being built throughout the country, these standard requirements have been relaxed almost unbelievably over what they were several years ago. We do that with the full realization of the economy involved, and also the importance of the structure and the relative ease with which we might be able to replace or repair that structure of minor importance over a period of years.

I have this closing thought. I would like to impress upon you that we do realize the difference, or the necessity for difference, in gradation requirements for natural fine aggregates and manufactured fine aggregates. That has been reflected in two big jobs. One will be opened sometime this month. The other will be advertised this month. Detroit Dam, in our Portland District in the Pacific Northwest, 460 ft. high, containing around 200 million yards of concrete, contains, for the first time in civil works history, two fine aggregate gradation requirements, one for natural materials and one for manufactured. We feel that both are essential, and since we do not know at this time whether we will use natural materials or manufactured—it may be natural sand and gravel or it may be basalt or diorite, all of them are under test—in order to permit a contractor to prepare his bid on a sound basis, we have opened the door and provided alternate fine aggregate gradations in that specification. That procedure will take place on more jobs as time goes on.

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